

HOW IT WORKS

Tablets and touch screens

While the mouse is considered a staple of office life, you don't always need one to hand. Tom Royal points out the technology behind graphics tablets and touch-screen displays, devices that get the job done without any mouse clicks

Most computing tasks are easy to accomplish with a keyboard and mouse. If you've ever tried to create a realistic painting, though, or place your signature on the bottom of an electronic document, you'll know that some things are nigh on impossible to draw with a mouse. Computers are also needed in locations where mouse controls aren't convenient, such as kiosks and ticketing machines. In this month's *How It Works*, we'll explain the technology behind two clever alternatives that give you the control you need without a mouse: graphics tablets and touch-screen displays.

KEEP TAKING THE TABLETS

Graphics tablets are, as the name suggests, most commonly used in digital graphics software. They are particularly useful in applications that mimic traditional art, such as Corel's Painter software, but a graphics tablet can also be useful for other tasks. Retouching photos is fairly easy with a mouse, for example, but can be easier and quicker still when using a tablet. Tablets currently available range from A5 and A6 pads, which are useful for signing documents, to A3 and even larger models for professional use.

The earliest graphics tablets used sound to measure the position of the pen on the tablet surface. Most used an electrically conductive tablet surface, and a pen tip that works in a similar fashion to a spark plug. When the pen was placed in close proximity to the surface of the tablet, a spark jumped across the gap, creating a clicking sound. Microphones on the tablet surface picked up this clicking sound, but at slightly different times according to the distance between the pen and each microphone. By measuring the time taken for the sound to reach each microphone and comparing these times, the computer could use triangulation to work out the position of the pen. This system was useful for marking individual points when entering plans or schematics into a computer, but with no way to measure the pressure applied by the pen on the tablet surface it was less useful for artistic uses. In any case, the problem of other sounds interfering with the microphone system, and the need for enough power to create sparks, rendered these acoustic tablets impractical for most uses.

The first graphics tablet to resemble those used today was developed by the RAND corporation in the early 1960s. The RAND tablet had an area of just over 10 square inches. It used a pen that was attached to a cable for communication to the computer, and was described at the time as "roughly the same size, weight and appearance as a normal fountain

pen". The pen contained a switch, so the operator could push it down on to the tablet to draw lines or shapes.

To track the movement of the pen over the tablet, the RAND system used a circuit board that contained, in effect, a grid of wires stretched horizontally and vertically over its surface. To transmit position information to the pen, electronics sent a series of pulses to each vertical wire, then to each horizontal wire. These pulses were synchronised to a set clock frequency, so for each cycle there were a number of set times at which any one wire could receive pulses of electricity. Each wire was sent a different string of binary data, encoded as pulses of current, so the pen could read its position as coordinates by receiving and decoding electrostatic pulses generated by the vertical and horizontal wires directly beneath it. This sounds complicated, but in fact it's relatively simple.

PEN PALS

Imagine we want to build a tablet that identifies which of three areas a pen is located over. A wire runs under the length of each of these areas, so we have three vertical wires. When the pen is over one of those wires, it can detect whether there is current flowing in the wire or not. Ideally, we'd want to send the value '1' down one wire, '2' down the second and '3' down the third, so the pen could read this and know its position. The wire has only two states, though (it either has current flowing or it doesn't), so we need to send this information in binary.

To do this, we send the signal '01' down one wire, '10' down the second and '11' down the third. This requires that two digits be sent sequentially, with a set period of time used to send each digit. If we use one second per digit, we'd first send power down the second and third wires for a second, then send power down the first and third wires for a second, then stop. If our pen receives a signal during the first period, followed by nothing during the next, this equates to the signal '10'. This is binary for 2, so we would then know the pen lies somewhere over the second wire.

This three-wired tablet contraption wouldn't be terribly useful, but it's easy to expand it to one that would. By overlaying a second set of three wires running horizontally, we can expand the system to identify a location in a 2D grid of nine points. By sending the same signals down the three horizontal wires after we have sent them down the vertical wires, we can provide a set of coordinates. If the pen receives the data 0110, for example, we'd know it lies above the first vertical wire (01), and the second horizontal wire (10), at point (1,2). By adding a signal after

our transmission that identifies the end of the coordinate sequence, then retransmitting the whole thing over and over again, we could track the movement of the pen as the user moves it from one point to the next. Finally, by using a lot more than three wires in each direction, we could produce a usable tablet area for drawing or writing.

The RAND tablet was, essentially, this same system on a grand scale. It used over 100 sensor wires per inch on each axis, and ran at a far faster clock speed so the location information was transmitted many times per second. Engineers also developed software to go with the tablet that was capable of recognising characters and flow-chart symbols, converting the hand-drawn input to neat letters and shapes onscreen. Its wired pen was less convenient to use than the wireless ones of today's tablets. However, the main obstacle that prevented it becoming common was price: with each unit costing \$18,000 (around £9,100), even those who could afford the huge cost of a computer couldn't necessarily afford a tablet to go with it.

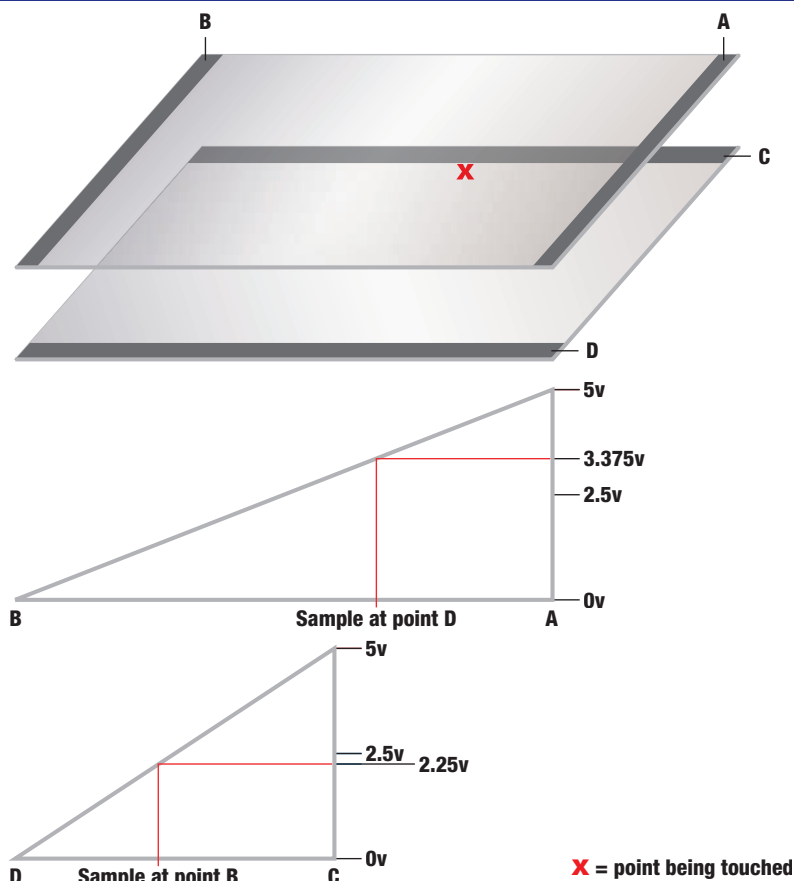
MODERN TIMES

Modern graphics tablets can be grouped into two categories: those that use an active pen and those that use a passive pen. Graphics tablets that use active-pen technology are fairly simple to understand. This type of tablet requires a pen that contains its own power source. This could be a rechargeable battery, but many cheaper tablets simply use an AAA battery that slots inside the barrel of the pen. This battery powers a tiny transmitter circuit that sends out a radio signal. The tablet itself contains a grid of wires that receive this signal. By analysing which parts of the tablet are receiving the strongest signal, the tablet can determine where on the tablet the pen is located.

In order to tell when the pen is pushed into the tablet, this system uses a sensor in the tip of the pen. When it detects pressure, electronics in the pen modulate the radio signal being emitted. This is then detected by the tablet, which passes on this information to the computer. Any other switches or buttons on the pen, such as a right-click button, work in the same way. Tablets with active-pen technology are becoming less common than they used to be, but a few are still available: the Genius G-Pen 450 (which we reviewed in *Labs*, *Shopper* July 2006) costs less than £30 including VAT.

Most tablets currently available on the market, and all Wacom's tablets, use passive technology. Passive tablets have the advantage of not requiring a power source in the pen, so you don't have to add, recharge or replace

Touchy feely How touch screens work



▲ To measure the location being touched, a voltage gradient is first applied between connectors A and B (upper graph). The voltage measured at edge D corresponds to the horizontal position. Next a voltage gradient is applied between C and D (lower graph), and the voltage measured from side B corresponds to the vertical position of the point being touched.

batteries. The exact details of Wacom's passive-pen technology are closely guarded, but enough information is available to give a good indication of how it works.

The technology in passive tablets is similar to that of the RAND tablet, but with the added complication that there's no wire connecting the pen and the computer. This means that rather than simply transmitting coordinates from the tablet to the pen, information also needs to be sent back from the pen to the tablet so it can be returned to the computer. Like the RAND tablet, modern passive tablets contain a grid of wires running horizontally and vertically under the surface. Unlike the RAND tablet, though, this grid of wires is used both to send and receive data from the pen. The pen itself contains a coil of wire and a capacitor.

The tablet's electronics alternate rapidly between a send mode and a receive mode. In the send mode, the wires in the tablet generate an electromagnetic field. This induces current in the coil of wire inside the pen. The tablet then switches to receive mode. The current moving in the pen's coil will itself generate an electromagnetic field, which induces a current in the mesh of wires beneath the tablet surface. By analysing the strength of the current induced in these horizontal and vertical wires, the tablet can deduce the location of the pen. A pressure sensor in the pen nib, and any other buttons on the pen, alter the circuit inside the pen by changing its capacitance. This alters the signal received by the tablet, so it can tell when

buttons are activated or the pen is drawing and advise the computer accordingly.

TOUCH AND GO

We also reviewed Wacom's Cintiq graphics tablet in our *Labs* round-up of graphics tablets (*Shopper* July 2006). This has a built-in LCD monitor, allowing you to draw or paint as you would on a pad or canvas, and uses Wacom's passive-tablet technology, with the tablet electronics underneath the LCD panel. Tablet PCs use a similar technology for their touch screens. The Cintiq is great for drawing and painting, but like any graphics tablet it requires that you use a special pen to draw or select areas on the screen, which makes it less useful for applications where you might want to make selections with a finger.

With this in mind, touch-screen displays of the type used in point-of-sale applications, information kiosks and consumer electronics use completely different techniques to determine which location is being touched. There are several commonly available touch-screen technologies, but many are confined to specialised uses where ruggedness is valued more than cost or weight. We'll explain the four-wire analogue resistance-based method that's used in most consumer touch-screen products.

Unlike the Wacom Cintiq, where the sensing technology is buried beneath the LCD screen itself, resistance-based touch screens use a standard screen with the touch overlay laid on top. The overlay consists of a controller connected to two layers: a flexible top layer

and a rigid bottom layer separated by invisible insulating dots. The layers are coated with a resistive transparent metal oxide coating. The top layer has silver ink bus bars running down its two vertical edges; the bottom layer has silver ink bus bars running across its two horizontal edges. The bus bars have a lower resistance than the metal oxide coating. Pressing the flexible top coating pushes the two layers together and creates a contact, allowing current to flow from one layer to the other.

To tell where a user has pushed, the system calculates the horizontal and vertical coordinates separately. First, for the horizontal coordinate, the left-hand side bus bar of the top layer is grounded and voltage is applied to the right-hand side bus bar. As the layer is a resistor, the voltage across it is a gradient, with voltage decreasing across the screen. Assuming that the input is 5V, the voltage near the right of the screen is 5V, the middle of the screen is 2.5V and the far left 0V.

When a user touches the screen, the top layer touches the bottom layer, allowing current to pass from the top layer to the bottom. The voltage reaching the lower bus bar on the bottom layer is measured. The voltage read tells the controller the horizontal position of the touch. As the bottom layer is sampling only a small amount of current, the voltage drop caused by the current flowing across its resistive coating is negligible.

Next, the screen calculates the vertical position in a similar way. First, the top layer is made inactive with no power running through it. The bottom bus bar of the lower layer is grounded and voltage is applied to the top bus bar, creating a voltage gradient down that layer with 5V at the top and 0V at the bottom. With the user still touching the screen, the voltage being transferred between the two layers at the point being touched is measured at the left bus bar of the top layer. This voltage tells the controller the vertical coordinate of the touch, so the full position is now known. The touch screen alternates between taking horizontal and vertical measurements in quick succession, so it responds rapidly to a touch.

The key advantages of resistance-based touch screens are simplicity and cost. They're easy to make, require relatively simple electronics and so cost very little. However, they can be damaged fairly easily and the two layers of conductive material above the display itself can impede the picture slightly. You'll usually find resistance-based touch screens in consumer electronics products, but products built to withstand regular use or abuse from the public tend to use more expensive and rugged systems that rely on ultrasonic waves or strain gauges. ☐

FURTHER INFORMATION

1964 memorandum explaining the RAND tablet

www.rand.org/pubs/research_memoranda/2005/RM4122.pdf

More information on RAND's character recognition

www.americanheritage.com/articles/magazine/it/2005/11/2005_1_55.shtml

Detailed description of analogue resistance-based touch-screen technology

<http://tinyurl.com/2z9qaj>